CREATING A PSEUDO SINGLE BUNCH AT THE ALS — FIRST RESULTS*

G. Portmann, S. Kwiatkowski, J. Julian, M. Hertlein, D. Plate,
R. Low, K. Baptiste, W. Barry, D. Robin

Lawrence Berkeley National Laboratory (LBNL), Berkeley, CA 94720 U.S.A.

Abstract

Typically storage ring light sources operate with the maximum number of bunches as possible with a gap for ion clearing. The Advanced Light Source (ALS) has 2 nanoseconds between bunches and typically operates with 276 bunches out of a possible 328. For experimenters doing timing experiment this bunch separation is too small and would prefer to see only one or two bunches in the ring. In order to provide more flexible operations and substantially increase the amount of operating time for time-of-flight experimenters, it is being proposed to kick one bunch on a different vertical closed orbit. By spatially separating the light from this bunch from the main bunch train in the beamline, one could potentially have single bunch operation all year round. By putting this bunch in the middle of the ion clearing gap the required bandwidth of the kicker magnets is reduced. To test this new method of operation on the beamlines one kicker magnet running at the ring repetition rate (1.52 MHz) has been installed at the ALS. This paper will show some first results running the kicker at 1.52 and 1.52/5 MHz.

INTRODUCTION

The concept of using a camshaft bunch started many years ago and originated out of the needs of time-of-flight experimenters. Some time ago, NSLS at Brookhaven experimented with kicking one bunch in the train at low repetition rates, [1]. This will introduce relatively long transient oscillations until the synchrotron radiation damps the bunch back to the closed orbit. To our knowledge no accelerator in the world has taken the next step to kick the camshaft bunch on a different closed-orbit to create a pseudo single bunch mode. Accelerators like the APS and ESRF can achieve similar functionality by installing choppers in the beamlines. However, even with state-of-the-art choppers this solution requires relatively large gaps in the bunch train, so it's presently only feasible on large accelerators. It also requires each beamline to purchase a relatively expensive and often difficult to use and maintain chopper. At the ALS the largest gap in the bunch train is presently 104 nanoseconds, which is out of reach for x-ray choppers.

There are a number of beamlines at the ALS interested in exploring a pseudo single bunch operational mode. A major reason is so that experiments using the camshaft bunch will not have to use gated detectors. The ability to use integrating detectors increases the variety and quality of the experiments that can be done. For instance, the combination of the pseudo single bunch mode and a chopper with an open time of just more than one turn allows for an effective single bunch operation at 1-10 kHz.

A POSSIBLE NEW OPERATIONAL MODE

By kicking the camshaft bunch on a different closed-orbit, it may be possible to create a pseudo single bunch operation during a multi-bunch user run. There are a number of different ways the orbit of the camshaft bunch can be shaped depending on the number and location of the fast kicker magnets. The easiest thing to do is install one kicker magnet and place the camshaft bunch on a different global closed-orbit. This may not be optimal for all single bunch or multi-bunch users, but it would be a relatively easy thing to do to experiment with the method. Another obvious thing to do is locally bump the camshaft bunch in one part of the ring. This would isolate the disturbance to a relatively small section of the ring. A third option is to install kicker magnets all around the ring and profile the orbit much like global orbit correction. This paper will show results for the one kicker scenario. A more detailed explanation of the entire system can be found in [2][3]. Details of the kicker magnet and pulser design can be found in [4].

GLOBAL ORBIT DISTORTIONS

The ALS is a 12 sector, triple bend achromat with 4.5 meter straight sections for insertion devices. A convenient location to install an experimental kicker happens to be in the straight section 2.

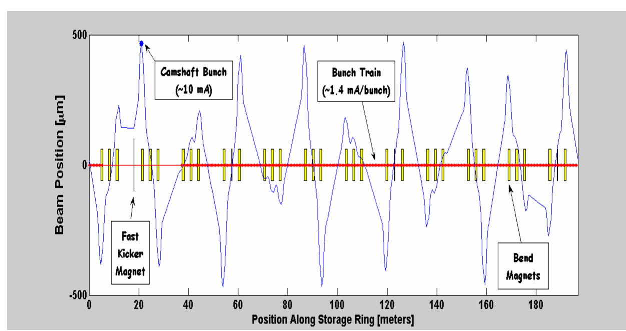

Fig. 1. Orbit Change for a One Kicker Magnet.

Using one fast kicker magnet running at the revolution rate (1.52 MHz) the camshaft bunch can be permanently

* This work was supported U.S. Department of Energy under Contract No. DE-AC03-76SF00098 and DE-AC03-76SF00515.

put on a different closed orbit. Fig. 1 shows the change in the closed orbit for the camshaft bunch for a 60 μradian kick (the design goal). As shown in the figure, this configuration would be suitable for a number of beamlines. Many of the outer bend beamlines and some of the insertion device and center bends beamlines would see a sizeable separation. Fig. 2 is the same data with the beam sizes included.

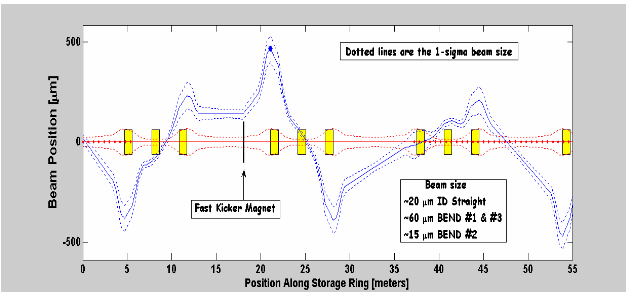

Fig. 2. 1- Kicker Magnet – First 3 Sectors.

BEAMLINE USER INPUT

A workshop was held to determine the user requirements for a pseudo-single bunch operation. The three basic issues are kick size (displacement), repetition rate, and contamination. There are also potential negative effects on storage ring operations.

Kick Size (displacement and/or angle)

The kick size is the required displacement or angle separation of the kicked bunch from the main bunch train. The present design calls for a 5-10 beam sigma displacement. This requirement could possibly be verified by scanning a closed-orbit bump in normal multi-bunch mode.

One of the challenges here is every beamline is different and the quality of the optics plays a big role in determining the required separation. Experimental data from BL 5.3.1 is shown in Fig. 3 for a beam sigma of .1 mm. Due to imperfect optics the beam profile distribution is only Gaussian to about 3.5 sigma. So there is only nominal improvement in bunch purity by kicking the beam past about 8 sigma. This beamline is roughly looking for a 10^{-3} reduction of the signal from the main bunch train.

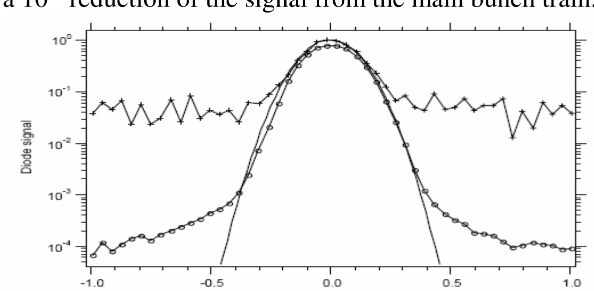

Fig. 3. Measured horizontal profile at BL 5.3.1 at 5 keV. The crosses and circles represent two amplifier gains and the line without symbols shows a Gaussian fit (Data provided by Robert Schoenlein).

* This work was supported U.S. Department of Energy under Contract No. DE-AC03-76SF00098 and DE-AC03-76SF00515.

Repetition Rate

The upper bound on the repetition rate is revolution frequency of the electrons – 1.5 MHz. Certain user experiments may require slower rates. For instance, experiments using lasers tend to be in the 1-10 kHz range. When using local bumps it is possible to run at any fraction of the revolution rate.

Contamination

There is a serious question about whether or not the multi-bunch users can handle this new beam profile.

- Contamination effects due to changes in the background radiation (not a Gaussian beam profile anymore).
- Effects of small periodic changes to the beam current in the main bunch train in the local bump case with frequencies less than 1.5 MHz.

Considerable attention will be given to understanding the contamination issues for each beamline.

Potential storage ring operational problems also need to be studied. For instance, the average orbit as reported by the beam position monitors (BPM) will change with the kick size and current of the camshaft bunch (which has a shorter lifetime). Non-repeatability of the kicker magnet would add noise to the bunch train and possibly a beam size increase due to diffusion. And if kicking at 1.5/n MHz, the transverse bunch-by-bunch feedback system would need to be modified.

FIRST RESULTS

A kicker magnet was installed in January 2008. Fig. 4 shows the difference orbit with and without the kicker on. A calibrated model was used to determine the 73 μradian maximum kick strength.

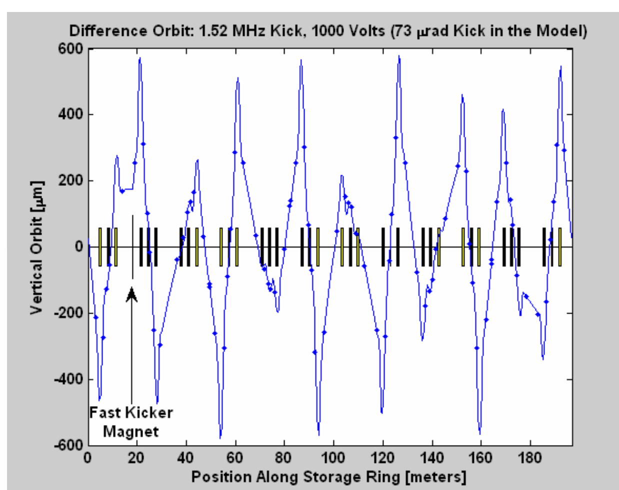

Fig. 4. Model (solid line) and measured (dots) difference orbit with the kicker at 1 KVolt.

When triggering the kicker every other turn, the effect at the synchrotron light monitor is quite obvious (Fig. 5).

Fig. 6 shows the model orbits at the location of the light monitor for this case.

Fig. 5. Synchrotron light image when kicking every other turn.

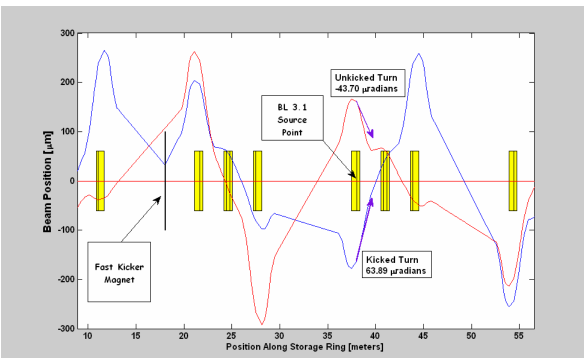

Fig. 6. Model orbits for each turn (1.5/2 MHz).

Reduce the Repetition Rate by 1.5/n MHz

If a beamline is not at favorable location with respect to a single kicker magnet in Sector 2 (Fig. 1), it may not be the end of the story. Being able to test this method on many different beamlines is extremely important. Instead of adding more kicker magnets, one can get interesting orbits by kicking at less than the revolution rate – 1.5/2, 1.5/3, 1.5/4, etc. When kicking at 1.5/n MHz it takes n turns for the orbit to close. Fig. 7 shows the closed orbits when kicking at 187.5 kHz (n=5). Since the electron BPMs measure the center of charge, the bottom plot in the figure compares the average of the 5 orbits in the model to the actual BPM measurement.

The picture gets quite confusing if one skips too many turns before kicking, however, this method can extend the reach of a single kicker magnet. For instance, a user in straight section six sees mostly an angle change in Fig. 1 but will see reasonable positional changes if kicking every fifth turn, Fig. 7.

Since the vertical fractional tune in the ALS is .2, kicking the bunch every fifth rotation will be in resonance with the beam. Basically, the $1/\sin(\pi\nu)$ term for a closed orbit change due to corrector blows up. If the tune was exactly .2, the bunch would be kicked out of the accelerator. However, if the tune is changed a small amount off .2, the kick will be just off resonance and a potential large amplification of the bump can be achieved. Fig. 7 shows the result for a vertical tune of 9.188. This factor of 3 amplification comes from $1/\sin(9.2\pi)= -1.7$ and $1/\sin(5*9.188\pi)=-5.33$ or 3.14 times the kick for free. There are two problems with using this method. First, all the different orbits in Fig. 7 may be a bit difficult to work with. That said, many of the beamlines would see one track which shows a large positional separation from all the other tracks. Second, the size of the orbit kick is directly dependent on the tune and the more amplification one tries to achieve the more sensitive it becomes to tune variation. For test purposes, one could also move the vertical tune to be on near resonance when kicking every 4th turn.

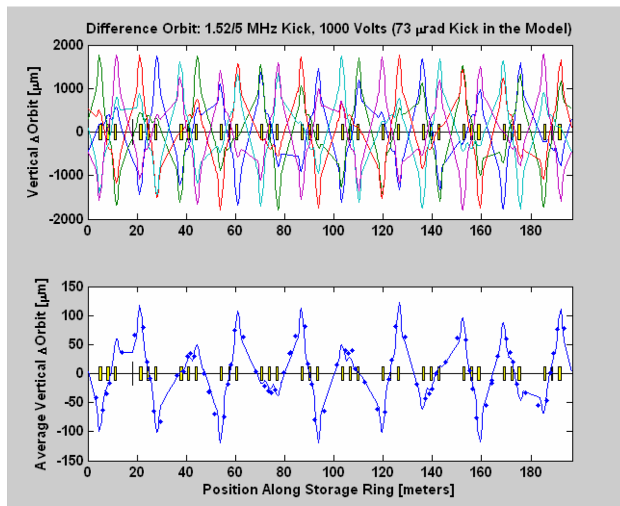

Fig. 7. Kicking Every Fifth Turn. Top plot shows the 5 model orbits. Bottom plot shows the average of the 5 model orbit as well as the actual difference orbits (dots).

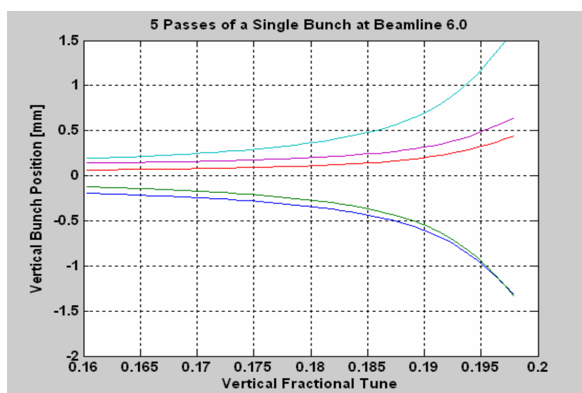

Fig. 8. Separation of the five passes vs. tune.

The first user experiment was done on beamline 6.0 (an insertion device BL located in the upstream end of sector 6 straight section). Fig. 8 shows the separation of the five separate passes of the singe bunch as a function of the tune. Fig. 9 shows the 1024 turns measured at a BPM just upstream of the beamline for various storage ring tunes. The turn-by-turn data is quite noisy however the separation of the different passes is quite apparent.

The profile of each of the five passes can be measured in the beamline using an avalanche photon diode, Fig. 10. The beamline data, the electron BPM data, and the model all agree reasonably well. However, Fig. 11 shows a limitation of this method. When the beam profile is measured at BL 6.0 for different tunes (this data was for pass #5), a large change in orbit is observed but the beam size also appears to change when approaching the resonant condition (.2 fractional tune). The cause of this increase is presently under investigation. A likely scenario is that the tune jitter translating to orbit jitter when sufficiently close to the resonances is too large. In the beamline orbit jitter looks like beam size blowup when integrating many turns with the APD. One particular power supply is responsible for most of the tune jitter in the ALS. It may be possible to improve the stability of this supply (or buy a new one).

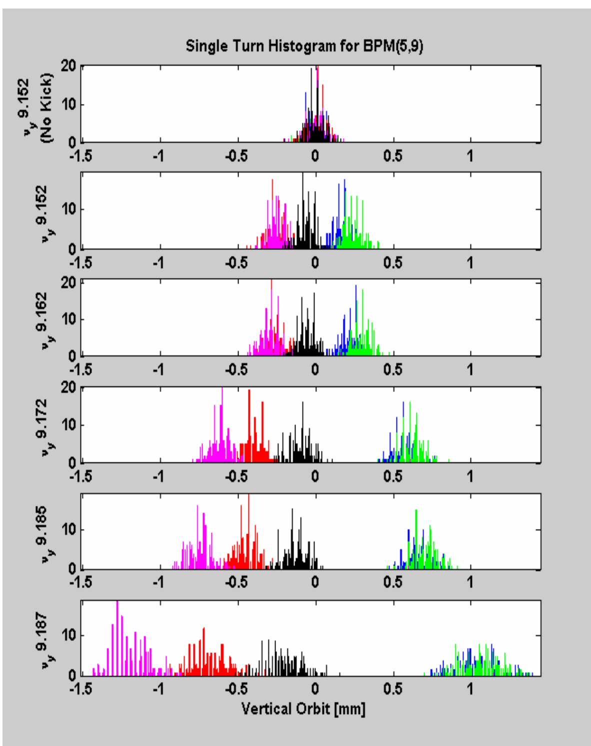

Fig. 9. Turn-by-turn BPM data for the 187.5 kHz (n=5) case. The vertical tunes are only approximate numbers.

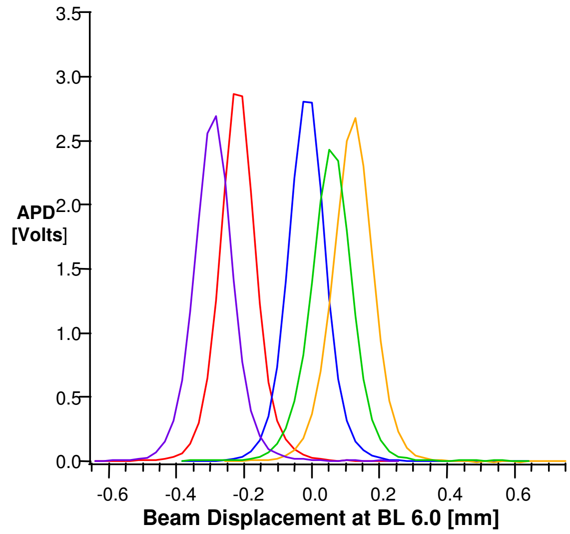

Fig. 10. Beam profile in BL 6.0 (tune ~9.162).

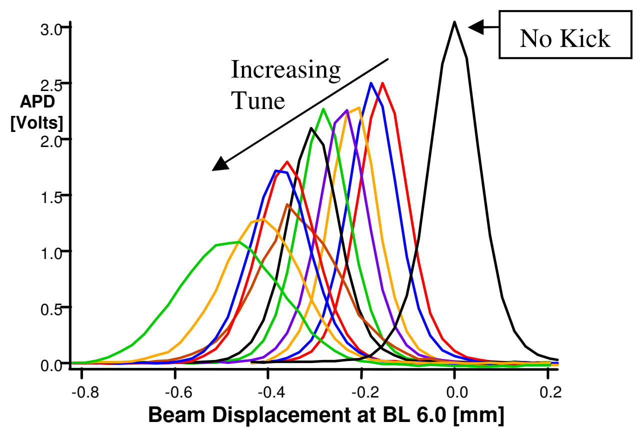

Fig. 11. Beam profile at different tunes for pass #5.

Repetition Rate Tradeoff

Unfortunately kicking at too low a frequency will produce some interesting but probably not useful beam characteristics. When kicking relatively slowly, a transient will be introduced which defuses in phase space (beam blowup) then finally damps back to the closed-orbit of the main bunch train.

The advantages of using a single magnet system is it takes up less than .5 m in the storage ring, it reaches a large number of users per kicker magnet, and it's relatively simple to operate. The disadvantage is it's a fixed frequency (1.5 MHz or a close fraction there of) and the fixed beam path may not be optimal for all users (or non-users). And the separation of the camshaft bunch from the main bunch train will vary depending on the beamline location.

FAST KICKER MAGNET DESIGN

The main parts of the fast kicker are the pulser and the magnet. The magnet is a stripline kicker similar to the fast feedback kickers which were designed at the ALS, Fig. 12.

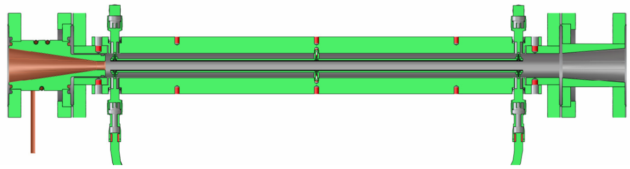

Fig. 12. Stripline Kicker

The pulser circuit provides the voltage to the kicker. The goal of the pulser is to supply high voltage when the camshaft bunch is present and zero volts the rest of the time. There was some hope of purchasing the pulser from industry but the 1.52 MHz requirement puts too big a heat load on all commercial units that were considered. For beamline requiring only 10 KHz or less repartition rate, there may be an off-the-shelf commercial unit with fast enough rise/fall time to meet the specification. However, running much less then 1.52 MHz can only be done using local bumps.

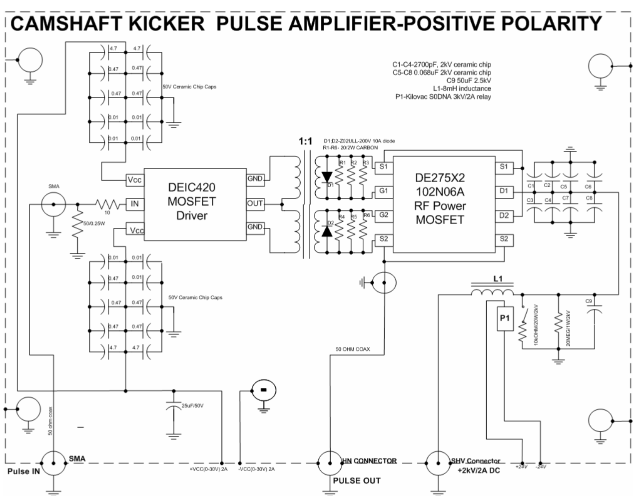

Fig. 13. Pulser Circuit (S. Kwiatkowski)

The circuit design for the pulser is shown in Fig. 13. It has a push-pull MOSFET pair that can run at 1.52 MHz (or less) and providing a 1 KVolts between the electrodes (1 kWatt average power, 10 kWatt peak power). Fig. 14 shows the pulse shape. At 45 nanoseconds there is potentially some room to reduce the gap in the bunch train if that is desired in the future.

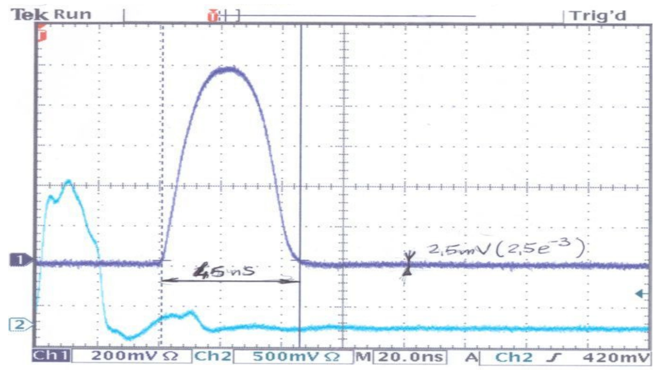

Fig. 14. Fast Kicker Pulse.

MORE TESTING

Depending on the operational mode and the location of the beamline with respect to the kick, there can be negative effects on beamlines using the multi-bunch beam. Since there are many beamlines with unique optics, it's difficult to predict the impact on every beamline. The next set of experiments with users at the ALS will be to study the benefits and contamination issues of this method.

ACKNOWLEDGEMENTS

We would like to acknowledge Brian Kincaid who suggested this approach many years ago and Janos Kirz for providing the support and encouragement to pursue it.

REFERENCES

[1] L. Blumberg, "VUV Wobbler," BNL Memorandum, May 29, 1980.

[2] G. Portmann, S. Kwiatkowski, D. Plate, J. Julian, R. Low, K. Baptiste, W. Barry, D. Robin, "Creating a Pseudo Single Bunch at the ALS," PAC, June 2007.

[3] G. Portmann, J. Kirz, S. Kwiatkowski, D. Plate, D. Robin, W. Barry, "A New Operational Mode at the ALS: Pseudo Single Bunch," 37th ICFA Advanced Beam Dynamics Workshop on Future Light Sources, Hamburg, Germany, May 2006.

[4] S. Kwiatkowski, W. Barry, J. Julian, R. Low, D. Plate, G. Portmann, D. Robin , "Camshaft Bunch Kicker Design for the ALS Storage Ring" EPAC'06.